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(54) Constructing profiles to compensate for non-linearities in image capture

(57) A chart having color patches, each color patch including information which permits the mapping of a digitized color image from an image captured by various means to construct a Profile usable in modifying the tone

scale and color of the digital image, the number of color patches being greater than 24 and being selected to compensate for non-linear characteristics of image capture.

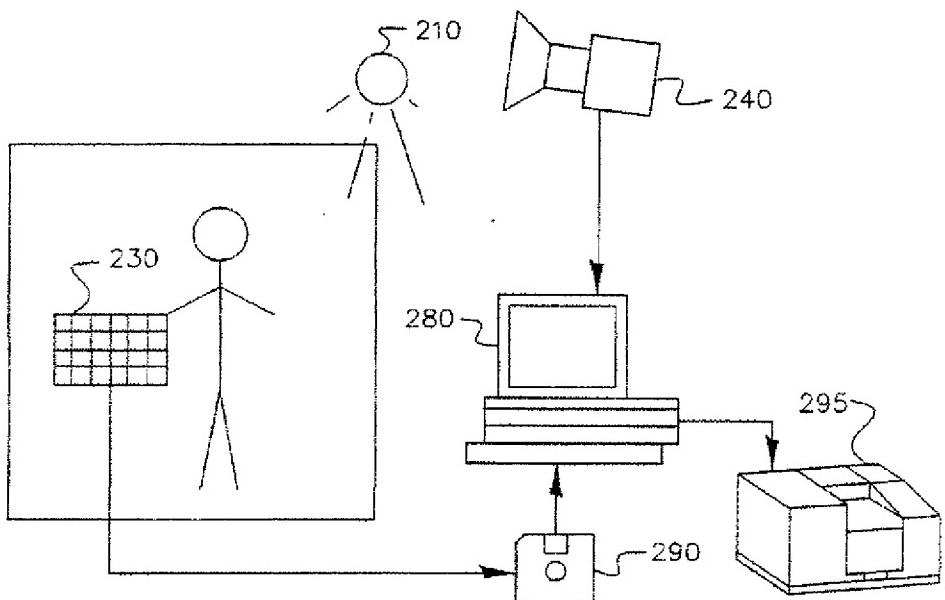


FIG. 2

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lightness and chroma. This was done in order to effectively sample a large scene color space. The neutral patches were composed of patches varying in lightness from white to black and are used for the tone and gray scale reproduction. The neutrals in this case were composed of spectrally nonselective pigments over the visual spectral range.

[0015] In the case of the reflective color patches, they were arranged on approximately an 8 x 10 inch board for portability and ease of use. The chart 130 was used as an element in a scene 120 illuminated by a light source 110 using conventional film capture. An image of the scene was captured by a conventional camera 140 on film 150 as a latent image record of exposures of the elements of the scene. The film was chemically processed (not shown) by conventional means to produce an image. The film image was scanned in a scanning device 160, resulting in digital code values for the picture elements (pixels). These digital values were input to a computer 180 containing a software program contained on a disk 190. The color chart was measured colorimetrically by a conventional spectrophotometer or colorimeter (not shown), and the resulting data supplied to the computer on the same disk 190 or by other means. The software program used the code values and the colorimetric data to construct a Profile. The term "Profile" means and refers to "a digital signal-processing transform, or collection of transforms, plus additional information concerning the transform(s), device, and data." (from *Digital Color Management*, Edward Giorgianni & Thomas Madden, Addison-Wesley, 1997). The Profile making process is explained in further detail below. Profiles made in accordance with the present invention were used by image processing computer software to produce a colorimetrically accurate reproduction or a preferred color and tone scale reproduction of the original scene by means, for example, of a color printer 195.

[0016] Referring to FIG. 2, a color chart 230 was used as an element in a scene 220 illuminated by a light source 210 using a digital camera 240 as a capture device in the imaging system. These digital values were input to a computer 280 containing a software program contained on a disk 290. The color chart 230 was measured colorimetrically by a conventional spectrophotometer or colorimeter (not shown), and the resulting data supplied to the computer on the same disk 290. The software program was employed using the code values and the colorimetric data to construct a Profile. This Profile was used to produce a colorimetrically accurate reproduction or a preferred color and tone scale reproduction of the original scene by means, for example, of a color printer 295.

[0017] Referring to FIG. 3, a Profile for a scanner 340 was directly created by scanning a chart 330. The digital values from the scan were input to a computer 380 containing a software program contained on a disk. The color chart 330 was measured colorimetrically by a conventional spectrophotometer or colorimeter (not

shown), and the resulting data supplied to the computer on the same disk 390. The software program used the code values and the colorimetric data to construct a Profile. This Profile was used by image processing computer software to produce a colorimetrically accurate reproduction or a preferred color and tone scale reproduction of the original scene by means, for example, of a color printer 395. It should be noted that, with this method, the scanner captures an image of any object, for example a painting, whose colors are not limited to those produced with a set of photographic dyes, and that the Profile created with the use of the said target permits a more accurate reproduction of the said object than has heretofore been possible with photographic dyes.

[0018] Digital imaging systems may typically employ a technique known as color management to provide the desired color and tone characteristics of an output image. An embodiment of this color management technique is diagrammed in FIG. 4B. The image is acquired by an Image Capture Device 440, which may be a digital camera, a film scanner, a print scanner, or other device. The digital Image Data 445 from the Image Capture Device is input to Image Processing Software 450 residing in a host computer (not shown). Also input to the Image Processing software are a Capture Device Profile 470 and a Display Device Profile 465. These Profiles contain information about the color processing characteristics of their respective devices. The Image Processing Software uses this information to produce Modified Image Data 460 which is then supplied to an Image Display Device 455. The Image Display Device may be a thermal printer, ink jet printer, electrophotographic printer, photographic printer, cathode ray tube (CRT) display, liquid crystal display (LCD), or other display device.

[0019] A Profile for use by a color management system is created by a process like that shown in FIG. 4A., where colorimetric data 410, often in the form of a target description file (TDF) for a target (not shown), is combined with digital Device Code Values 420 relating to the same target in a mathematical process such as Least-squares Regression 415 to produce a mathematical model such as a Polynomial Model 425. This model was then used to construct a Profile 430 containing one or more transforms and other data describing the device.

[0020] In the case of an image capture device, the colorimetric data is typically obtained by measuring with a spectrophotometer or colorimeter a target which is then captured by the image capture device. The image capture device produces a digital image of the target, from which the device code values are obtained. In the case of an image display device, the process is reversed; device code values for a digital target image are supplied to the device, which then produces a real image, either hard copy in the case of a printer, or softcopy in the case of a CRT or LCD. The colors of this real image are then measured with the aforesaid spectrophotometer or colorimeter. In either case, colorimetric data and device code values are combined in the process

[0027] Once an appropriate model has been determined, the corresponding look-up tables can be used as part of a profile for the imaging device. In this case the look-up tables create a direct association between the signal-processing stage and the imaging device.

[0026] The benefits of reducing the number of patches in the chart to the degree of compatibility and non-lineararity of the capture device being modeled. The use of more patches results in a better prediction of performance of a complex, non-linear device; and a simple, more complete chart which is easier to make and use, is simpler, more compact, more concise, and more useful.

[Q0025] An upper limit for the chart is determined by two factors. One is a practical limit of the overall physical dimensions of the chart for portability and ease of use. It should be recognized that the individual patches must be large enough to facilitate measurement by spectrophotometer or colorimeter and to be easy to discriminate as components of an image. A 9 x 12 inch chart of three hundred patches typically satisfies these criteria. Two is that most input devices can be adequately modeled with polynomials having 25 to 50 terms, and 300 patches is probably sufficient to constrain the fit of such a polynomial model. It is also helpful to include additional hues beyond the six primary colors previously mentioned.

neural patches depends upon a number of factors in-
cluding system non-linearity; that ten percent of the total
number of patches should be neutrals has been found
generally adequate with targets of several hundred
patches, but when the total number of patches is less
than 60, a larger proportion should be devoted to neu-
trals. The well-known Macbeth Color Checker, for ex-
ample, has 24 patches, of which six (25 percent) are
neutrals. At least one neutral patch, preferably of visu-
ally average lightness (18 percent reflectance), is very
useful to serve as a reference value throughout the me-
asuring system from input device to output device.

[0023] It is worthwhile to note the significance of including neutral patches in the artificial chart. Persons skilled in the art will appreciate that achieving correct reproduction of neutrals in an imaging system is of great importance. It is therefore recommended that this invention be included in the large majority of patch sets to reduce the errors introduced by the model to fit associated with neutrals. The required number of patches is dependent on the size of the chart and the resolution of the sensor used.

35 patches, which in turn provides better results than 100 color patches composed of 200 colormetrically well placed color patches provided by non-linear systems. That is to say, a model complex, non-linear system is able to address the ability to model proven to work well in increasing the quality of colors have been charts with an increasing plurality of colors have poor color predictions for colors not on the color charts. Color charts stem from erroneous results. The erroneous results and prevent data points to support the modeling process and prevent 40 tencies within the polynomial modeling requires enough look-up table. However, increasing the number of color patches significantly of the subsequent three dimensional increased accuracy in a better model and in effectiveness of the imaging device. Increasing the number of color patches of the imaging device, increasing the number of color patches, which in turn provides better results than 25

[0022] Referring to FIG. 4A, common to more com-
plex imaging devices is an internal non-linear sys-
tem relationship between the Device Code Values 420 of the
captured digital image and the (coordinometric) data 410. This
can be the result of sensor interaction with light, in the
case of digital capture, or chemical interaction with light,
in the case of film capture, or a combination of these
systems. The extent of the non-linearity is dependent
on the intricacies of the given imaging system. Non-lin-
earity in an imaging system presents a difficulty in mod-
eling the system mathematically, in simple imaging de-
vices, a simple one dimensional look-up-table will permit
a channel by channel correction until suitable results are
computed. In more complex non-linear devices, three
dimensions must be employed to ac-
count for non-linearity within a color channel but also
non-linearly between color channels. Polynomial mod-
eling 425 has successfully been used to create robust
three dimensional look-up tables. The use of compre-
hensive polynomial modeling algorithms in conjunction
with supporting information from well designed color
charts, permits three dimensional look-up tables to be
built for non-linear devices. The polynomial modeling
uses adjustable coefficients to represent the non-linearities.

[0021] The file format for Profiles, and to a certain degree the architecture for mage processing software using them, is the subject of a standard developed by the International Color Consortium (ICC) now widely adopted in the industry. The standard may be downloaded from the ICC web site, <http://www.color.org>; it will be understood by one skilled in the art that the present invention can use the ICC system but is not limited to such.

transform. This Profile is then used to subsequently convert images obtained with the capture device and convert them to the original scene colorimetry or to a preferred color or tone scale rendering.

[0028] It is well known to those skilled in the art that the colors reproduced on, or produced from, common color image capture devices generally are not colorimetric matches of the colors originally captured by the element. Colorimetric errors can be caused by the color recording and color reproduction properties of the capture element and system. The distinction between the color recording and color reproduction properties of a capture element is fundamental. Color recording by a color imaging device is determined by its spectral sensitivity. The spectral sensitivity of a capture element is a measure of the amount of exposure at a given wavelength required to achieve a specific capture response. Color reproduction by an imaging system depends not only on the color recording properties of the capturing element as described above, but also on all subsequent steps in the image forming process. The color reproduction properties of the imaging element or system can vary the gamma, color saturation, hue, etc. but cannot fully compensate for problems caused by spectral sensitivities which are not correlates of the human visual system. Metamers are an example of such a problem. Metamerism occurs when two stimuli with different spectral reflectance appear identical to the eye under a specific illuminant. The term "Metamer" is defined as "property of two specimens that match under a specified illuminator and to a specified observer and whose spectral reflectances or transmittances differ in the visible wavelengths" (as described in *ASTM E 284, Standard Terminology of Appearance*). A capture device whose spectral sensitivities differ from that of the human visual system records the stimuli differently. Once recorded as disparate, a capture device's color reproduction will only amplify or minimize that difference.

[0029] In certain applications, it is desirable to form image representations that correspond more closely to the colorimetric values of the colors of the original scene recorded by the capture device rather than form image representations which correspond to the reproductions of those colors by the device itself. Examples of such applications include, but are not limited to, the production of medical and other technical images, product catalogues, magazine advertisements, artwork reproductions, and other applications where it is desirable to obtain color information which is a colorimetrically accurate record of the colors of the original scene. In these applications, the alterations in the color reproduction of the original scene colors by the color recording and color reproduction properties of the imaging element are undesirable.

[0030] Broadband colorants were used so as to approximate real world colorants common to scene elements typically captured by film systems, digital camera systems, and to a lesser extent, digital scanning sys-

tems. The broadband colorants minimize metameric differences caused by different illumination devices. Narrow band colorants used in the chart would have been more prone to metameric induced errors.

5 Example 1: Color chart captured using color negative or color positive film and subsequently scanned.

[0031] A color negative film was scanned. The scanning of that color negative films result in a non-linear relationship between the output code values of the scanner and the original scene colorimetry. It has been determined that adequate accuracy within the color modeling could be significantly improved by increasing the number of color patches. Therefore, a more robust technique was sought incorporating more patches and subsequently a better sampling of color space. A color chart containing 264 patches of approximately ten hues of varying lightness and chroma was made. Due to the adequate color sampling of the color patch collection, the Profile modeling technique provided a robust Profile for this non-linear imaging system.

Example 2: Color chart captured using a digital camera.

[0032] An image of the scene was captured using a Kodak DCS460 digital camera. The resulting digital code values for the picture elements (pixels) of the images were input to a computer. The color chart was previously measured colorimetrically by a conventional spectrophotometer or colorimeter, and the resulting data supplied to the same computer as the digital image. The software program used the code values of the digital image and the colorimetric data to construct a Profile. This Profile was used by image processing computer software to produce a colorimetrically accurate or preferred color rendition reproduction of the original scene by means, for example, of a color printer.

40 Example 3: Improvements in Profile accuracy using a larger patch set.

[0033] In characterizing a scanner as a real world colorant input device, the quantity of patches was compared for resultant color accuracy. For those skilled in the art of color, the metric of CIELab ΔE was used to characterize system performance. This metric incorporates both lightness and color error and is common to color science practices. Color accuracy data was calculated using a 24 color patch set and a 264 color patch set. The mean error using the 24 patch set was 3.66 ΔE for the Profile development. The mean error of the 264 patch set was 2.23 ΔE . This improvement demonstrates the reduction of color error in using larger color patch sets for Profile generation.

7. The method of claim 3 further including the step of forming one or more prints of the modified digital image.
6. The method of claim 3 further including the step of forming one or more prints of the modified digital image.
5. The method of claim 3 wherein the color patches include at least one neutral patch.
4. The method of claim 3 wherein the elements include a film element, scanning devices including an image sensor, or electronic images provided from another source.
3. The method of claim 3 further including the step of acquiring a digital image and a chart having more than 24 color patches including information which permits mapping the colors from the digital image, the number of color patches being selected to accommodate for non-linear characteristics of elements in the acquisition process;
- (a) acquiring a digital image and a chart having more than 24 color patches including information which permits mapping the colors from the digital image, the number of color patches being selected to accommodate for non-linear characteristics of elements in the acquisition process;
- (b) constructing a profile from the acquired image; and
- (c) using the profile to modify the acquired digital image,
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3. A method of producing an improved digital image comprising the steps of:

2. The chart according to claim 1 wherein the spectral characteristics of the colorants used to construct the chart are selected to enhance the effectiveness of the profile.

1. A chart having color patches, each color patch including information which permits the mapping of a digitized color image from an image capture in various means to construct a profile usable in modulating the tone scale and color of the digital image.

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4. Visual comparisons of images processed through profiles for the same imaging device using broadband pigments and narrow band dyes showing significantly better than using a chart of known narrow bandwidth for use in generating a profile for a device capturing a real world colorants.

Example 4: Improvement in Profile Accuracy using broadband pigments.

8. The method of claim 3 wherein the number of color patches is between 60 and 300.

[0034] Visual comparisons of images processed through profiles for the same imaging device using broadband pigments and narrow band dyes showed a significant color quality difference. Using a chart of known broadband pigments was shown to work significantly better than using a chart of known narrow bandwidth for use in generating a profile for a device capturing a real world colorants.

Claims

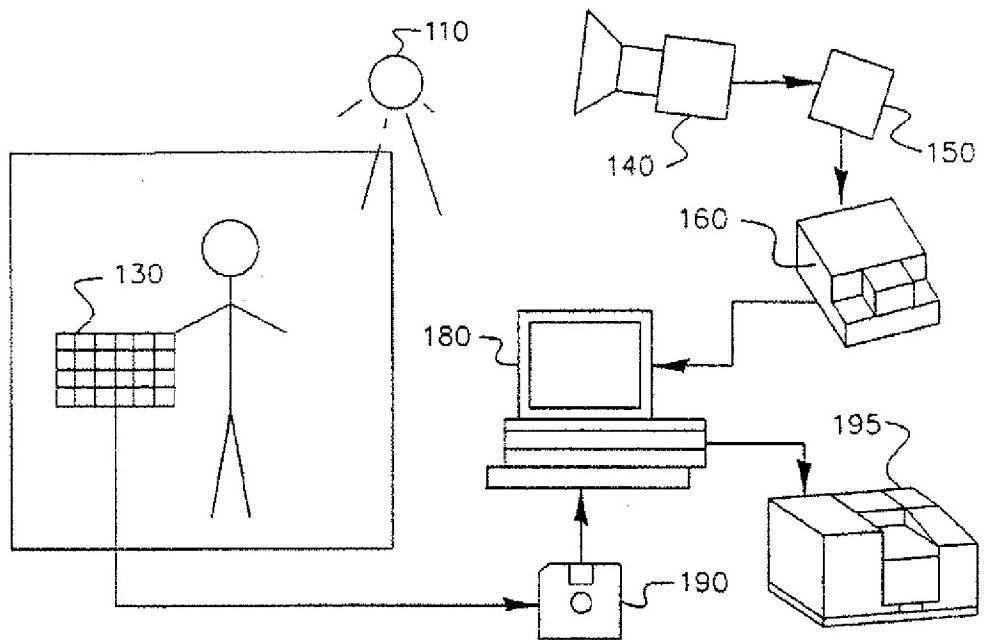


FIG. 1

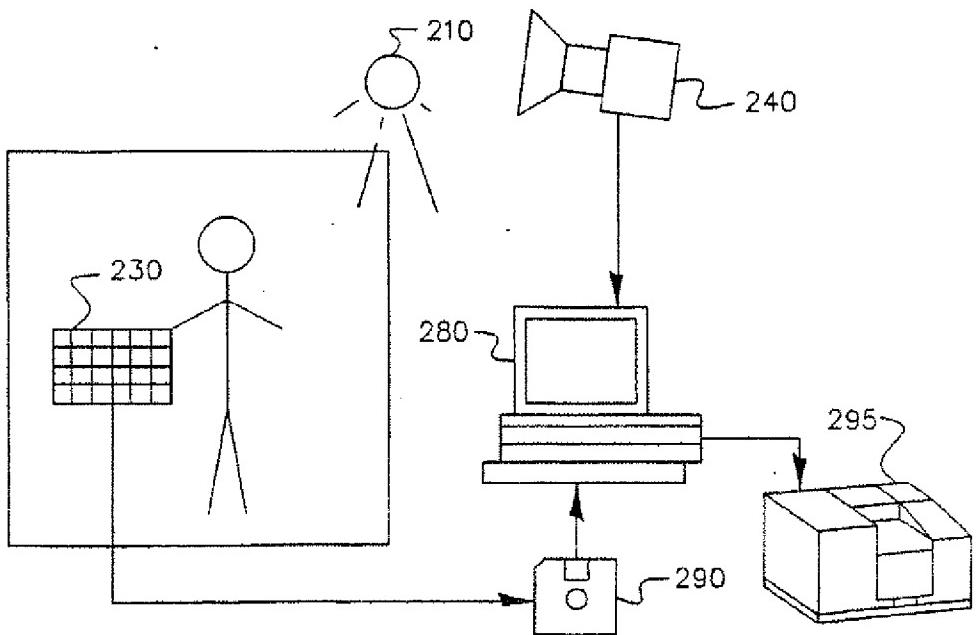


FIG. 2

